VOLUME 37 JULY 1953 NUMBER 7

NBS Institute for Numerical Analysis

TECHNOLOGY

A NEW science of computation, designed for use with modern high-speed electronic computers, is taking form. Based on a combination of the older hand-machine computing techniques with the results of new mathematical theories and methods of analysis, the new science is providing a reservoir of mathematical knowledge that can be drawn on for innumerable applications by users of large-scale automatic computers.

Research and development in numerical analysis—the branch of mathematics dealing with numerical calculations—requires intensive theoretical study based on a broad background of pure mathematics. However, before the advent of modern high-speed computing machines, numerical analysis was unfashionable among professional mathematicians, and its development had lagged far behind other mathematical disciplines. To conduct the theoretical and applied investigations in this field that are necessary in order to fully utilize the postwar developments in automatic computing, the National Bureau of Standards Institute for Numerical Analysis (INA) was established early in 1948 as part of the Bureau's program in applied mathematics and computing machine development. The INA now has a permanent staff of about 70, supplemented by visiting scholars from universities and other research organizations who are permitted to use the facilities of the Institute.

The INA is one of four laboratories that make up the Bureau's Applied Mathematics Division, organized in 1947 with the support of the Office of Naval Research to provide a centralized national mathematics laboratory. The Division also includes a computation laboratory, which provides a general computing service for other NBS divisions and other Government agencies; a statistical engineering laboratory, which provides consulting service on modern statistical methods as applied to the physical sciences and engineering; and a machine development laboratory.

With the support of the Office of Naval Research, the Air Research and Development Command, and the Air Comptroller, the INA has not only pursued intensive theoretical studies in those phases of applied mathematics that have been hampered by lack of suitable numerical techniques but has also conducted research in fields related to the design and construction of large-scale computers. In the course of this work, SWAC (National Bureau of Standards Western Automatic Computer) has been successfully completed under the sponsorship of the Wright Air Development Center and put into useful operation.

The INA provides a computing service for other Government agencies and especially for their contractors in the Southern California area, solving many problems of aircraft design that originate there. It also maintains a consulting service on special problems in applied mathematics and conducts training programs in the theory and application of high-speed automatic computing. However, the primary function of the Institute is to parallel the development of automatic digital computing machines with theoretical investigations aimed at finding how best to use the machines as they become available. A computing machine can perform only a limited number of operations—such as addition, multiplication, comparison of two numbers, and the like—and then only on the basis of definite instructions prepared for it by a mathematician. Once the physicist has expressed his problem in the form of equations, he requires the aid of a

259376°—53

mathematician who can translate the problem into a form involving only those operations that the available machine can perform. This often involves extensive and complex mathematical procedures. Indeed, many types of physical problems exist that cannot be translated into forms acceptable to current machines by any presently known mathematical techniques. The major portion of the research at the INA is directed toward the solution of this type of problem through the development of new procedures in numerical analysis.

In order that the new methods thus developed may be tried out and checked in actual practice, the research worker in numerical analysis must have access not only to computing machines of the latest design but also the most up-to-date information regarding research in machine development throughout the world. For these reasons, it was felt desirable to carry through the complete design, development, and construction of a large-scale automatic digital machine at the INA. This program resulted in the completion of the SWAC, an extremely high-speed general-purpose machine using the very rapid cathode ray-tube memory. Through the use of the SWAC in combination with the Institute's modern punch-card computing machinery, solutions are rapidly being obtained for problems in science and engineering that would have required a prohibitive amount of time by desk-machine methods.

In the mathematical research program of the INA, major emphasis has thus far been placed on techniques for the solution of simultaneous equations, the inversion of matrices and the determination of their characteristic values, and methods of integrating partial differential equations—topics important in the solution of many problems in aerodynamics and other branches of physics. Considerable attention has also been given to the use of probability methods in numerical analysis, the use of numerical methods in conformal mapping, and the mathematical theory of program planning. In addition to these major efforts, the Institute has carried out research on probability methods and sampling techniques and has made a number of miscellaneous studies in applied mathematics and theoretical physics.

Problems in least squares, reduction of data, heat transfer, stress analysis, and a tremendous variety of other physical problems can be described in terms of linear equation—algebraic, differential, or integral. Regardless of the nature of their basic equations, the (approximate) numerical solution of such problems for physics and engineering applications can be reduced in every case to a single standard problem—the solution of large systems of simultaneous algebraic equations. For example, in order to design the stiffeners for an airplane wing in such a way as to avoid possible elastic failure, it is important to know the elastic stresses exerted by the wind and the weight of the plane when the plane is moving with steady speed under steady atmospheric conditions. This problem can be reduced to the solution of a large set of algebraic equations. The Institute for Numerical Analysis has done intensive research directed toward the development of practical techniques for the solution of large-scale algebraic equations on electronic digital computers.

Actually, however, no flight is ever completely static. Apart from the take-off and the landing, when the speed is constantly changing, accidental air currents and other small dynamic influences cause aerodynamical forces that excite the elastic vibrations of the structure during the steady phase of the flight. Unless the amplitudes of these vibrations remain within certain limits, they may generate stresses large enough to cause the failure of an entire wing. This is an example of another large class of problems—those that involve the "characteristic vibrations" of an elastic structure or an electric circuit.

Analysis of these characteristic frequencies has been found mathematically equivalent to a determination of the characteristic values of a matrix. Unfortunately, the matrices involved in a realistic imitation of the actual physical situation are frequently of such high order as to be impractical of solution by desk-calculator methods. For this reason, it has been necessary in the past to depend on rather crude approximations, or else on the performance of model experiments, which are costly and yet not always of the desired degree of accuracy. Procedures have now been worked out which determine the characteristic values of matrices of orders much larger than could previously be handled.

The mathematical technique known as conformal mapping is of special interest at this time because of the many crucial problems now demanding attention in the design of high-speed aircraft, jet planes, guided missiles, and rockets. Many of the problems arising in these fields are difficult because they involve areas or solids of irregular or inconvenient shapes. Often the irregular areas or solids can be mapped conformally—that is, without altering angles—onto very simple figures, such as circles or spheres. When this has been done, the problem can usually be solved more easily, and the solution for the original shape can then be found by reversing the mapping process.

In the past, because of the mathematical difficulties in setting up the correct maps, conformal mapping problems have been solved largely through the use of cumbersome and slow graphical methods, which provide only approximate answers. Numerical methods had not been used because of the insuperable difficulties and labor involved. Now, however, the advent of electronic computing machines offers extraordinary new facilities for rapidly constructing maps if only the appropriate mathematical routines can be developed for the machines. Research in this field may ultimately make possible full exploitation of the techniques of conformal mapping, eliminating in many cases the use of vast experimental facilities such as wind tunnels and the attendant costly and laborious experimental work itself. This in turn would mean the rapid solution of key problems in aerodynamics, including rocket and guided missile design, as well as gas and fluid dynamics and electromagnetism.

A large amount of theoretical research has been done by NBS on the mathematical theory of program plan-

Punched-card calculators are used at the NBS Institute for Numerical Analysis to solve those problems which are too large for manual computing methods and yet are not large enough to make the use of an electronic digital machine practical. When a deck of punched cards is run through one of these machines, it reads several numbers from each card, performs a prescribed sequence of additions, subtractions, multiplications, or divisions, and punches one or more of the answers obtained into unused portions of the card. It will also, if desired, store some of the answers for use in connection with data read from the next card.

ning, and a number of computational experiments have been carried out. Sponsored by the Air Comptroller's Office and the Air Research and Development Command, this work has as its object the application of automatic digital computing to the science of management. The ultimate aim is to make use of mathematics to devise purely mechanical processes that may be used to replace the thousands of individual human decisions involved in a major management program. For example, in achieving a given volume of production or in deploying a certain number of troops and equipment at a given date, it is necessary to procure machines, transportation, materials and supplies, spare parts, and fuel and to provide for the training of operating and supervisory personnel. The personnel requirements in the levels of activity involved at each step have hitherto been the subject of a multitude of separate decisions arrived at by "educated guessing" on the part of different individuals. The present program aims to develop methods of replacing these decisions by high-speed mathematical computation. Methods are being tried out using the most up-to-date computing equipment available, and further methods will be tested as better and faster computing machines become available in the future.

The INA has also done pioneering research in the application of the so-called Monte Carlo method to the solution of complicated differential equations as well as certain statistical problems in nuclear physics that have eluded solution by ordinary scientific methods. The Monte Carlo method, developed by J. von Neumann of the Institute for Advanced Study at Princeton and S. Ulam of Los Alamos Scientific Laboratory, may be described essentially as a new mathematical technique, which solves a physical or mathematical problem by creating an artificial statistical model of the physical or mathematical process involved. It applies the same techniques that are used in analyzing games of chance to the analysis of physical problems where the events are random and are governed by the laws of probability.

The development of peacetime applications of atomic energy provides an interesting example of the utility of this method. One of the biggest problems in the design of an atomic pile is that of proper shielding against the dangerous radiations caused by collision of high-energy neutrons. To determine experimentally the proper shielding material and its most adequate dimensions would require a great deal of research with different types of piles, fission rates, and other variable conditions, and even then the results would probably be merely estimates based on an insufficient number and variety of experiments. On the other hand, the law which governs the motion of the neutrons is known in a general way, and this law is of a purely statistical kind. Each individual neutron moves somewhat like a drunkard who has lost control of his muscles and is driven by accidental impulses. A walk of this nature is known as a *random walk*. However, even though it is random, it is not a lawless process. For, although the result of one individual event cannot be predicted, the result of a large number of repeated events can be forecast with remarkable accuracy. Thus it is possible to set up a statistical model of the problem from which valuable data may be obtained without the necessity of expensive and time-consuming experimentation.

Large-scale electronic computers such as SWAC provide an excellent means for the solution of problems of this kind because they are able to create conditions that imitate the statistical behavior of the given problem. Thus, the randomness of the event can be taken care of by putting into the extended memory of the machine a set of random numbers that are first tested

SWAC (National Bureau of Standards Western Automatic Computer) was designed and constructed by the INA staff to provide a tool for research in numerical analysis. SWAC's high speed results from its very rapid cathode-ray-tube type of memory (center background). Input mechanism is at left; output mechanism, at right.

for their random quality. After the special conditions that govern the statistics of the process under study (the "rules of the game") have been placed in the memory, the machine is put into operation, going through millions of "random walks" in a matter of minutes. The digital machine can thus serve as a substitute for an otherwise very complicated and tremendously expensive atomic experiment. Because the problem can be repeated many times on the computing machine under slightly different initial conditions, the experiment with the mathematical model is not only much less dangerous and expensive but also more varied than would be actual experimentation with the original pile.

By the use of SWAC, the INA has been able to compile large groups of random digits, to explore their statistical behavior, and to investigate their utility for solving partial differential equations by random-walk processes. Recently problems concerning nuclear forces have been attacked through random-walk experiments. If the statistical rules which best fit the experimental results of certain scatter experiments can be found, an insight will have been gained into the nature of the nuclear forces which are responsible for the scatter. However, much mathematical theory remains to be worked out and a great deal of numerical experimentation must be performed before the Monte Carlo method can be used with advantage in the solution of a wide area of problems. Work on these phases of the method is continuing at the INA.

Comprehensive accounts of the current status of some of the major fields discussed above are given in the following publications of the NBS Applied Mathematics Series (available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.): AMS18, Construction and applications of conformal maps, *proceedings of a symposium held June 22–25, 1949, in Los Angeles, Calif. (1952), $2.25; AMS29,* Linear simultaneous equations and the determination of eigenvalues, *proceedings of a symposium held on August 23–25, 1951, in Los Angeles, California, in press. See also AMS12,* Monte Carlo method, *proceedings of a symposium held on June 29, 30, and July 1, 1949, in Los Angeles, Calif. (1951), 30 cents; AMS15,* Problems for the numerical analysis of the future, *four papers presented at the Symposia on Modern Calculating Machinery and Numerical Methods, held in July 1948 in Los Angeles, Calif. (1951), 20 cents.*

New Viscosity Standard Adopted

BEGINNING on July 1, 1953, NBS will adopt the value of 0.01002 poise for the absolute viscosity of water at 20° C as the primary standard for the calibration of standard viscosity samples and viscometers. The date originally proposed for this change was July 1, 1952; but, at the request of the American Society for Testing Materials and the International Organization for Standardization, the adoption of the new value for water was deferred for one year in order that the ASTM and ISO members could make the change simultaneously with NBS. The ASTM, the National Physical Laboratory in England and the Physikalisch-Technischen Bundesanstalt in Germany have indicated that they will also adopt the value of 0.01002 poise on July 1, 1953.

Up to the present time the value of 0.01005 poise for the absolute viscosity of water has been used widely as the primary reference standard. The use of the new value of 0.01002 will result in a reduction of 0.3 percent in the measured values of viscosity and will make viscosities reported in absolute units correspondingly more accurate. Previously published data based upon 0.01005 poise may be adjusted to the new standard by reducing the published values by 0.3 percent.

For details concerning the determination of the new value of viscosity, see The absolute viscosity of water at 20° C, *by J. F. Swindells, J. R. Coe, and T. B. Godfrey, J. Research NBS* **48** *(Jan. 1952) RP2279; also see NBS Tech. News Bull.* **36,** *3 (Jan. 1952).*

Electron-Beam Interferometer

RESEARCH on the wave properties of electrons has resulted in the development of an interferometer that utilizes electron beams to produce interference fringes in much the same way as conventional optical interferometers use light beams. The electron-beam interferometer, developed by L. Marton, J. Arol Simpson, and J. A. Suddeth of the National Bureau of Standards, employs diffraction from an extremely thin crystal as a means for splitting and recombining an electron beam and uses an electron optical system for viewing the resulting interference phenomena.

The NBS electron interferometer greatly extends the range of light interferometers used in the direct measurement of length. In addition, the instrument constitutes an extremely sensitive device for measuring gradients of magnetic and electrostatic fields—analogous to refractive indices in optical interferometry—and provides a means for obtaining additional information on the wave nature of the electron. Other suggested applications of the method include studies of the energy levels in solids and an absolute determination of Planck's constant.

The first experimental evidence for the wave nature of the electron was reported by Davisson in 1927. Since that time a large volume of work with electron diffraction has amply demonstrated the phenomenon of interference of electron beams. In principle, an electron-beam interferometer could be based on the equivalent light-optical experiment of Young in which the double-slit method is used to split the wave front. However, because of the short wavelength, the size of the source, the size of the slits and their separation, and the small separation of the fringes, a major experimental effort would be required, with doubtful expectation of success. A more promising approach (and the one upon which the NBS electron interferometer is based) is the use of amplitude splitting, a wide-beam technique such as that employed in the Michelson interferometer.

One of the major components of the wide-beam electron interferometer developed by NBS is a system of extremely thin crystals that diffract and transmit the beam of electrons. The crystals are mounted in a vacuum chamber placed between the illuminating and viewing systems of a conventional electron microscope. Assume that a beam of electrons has passed through the exist aperture of the electron gun and is incident on the first of three crystals. Because of the regular atomic configuration of the crystal a part of the beam is diffracted and part is transmitted directly through the crystal. A second crystal, less than 5 cm in front of the first, is of such dimensions and so positioned that it accepts only the transmitted beam and one of the first-order diffracted rays. An aperture between the second crystal and the third, which is placed at a distance equal to the separation of the first and second crystals, limits the electron beam to only those portions of the two rays incident on the second crystal that are diffracted into a first order. An aperture following the third crystal passes only the doubly diffracted first-order ray of the beam transmitted by the first crystal and the doubly diffracted first-order ray of the beam diffracted by the first crystal. The total path of these twice-diffracted, once-transmitted rays is similar to a parallelogram with two very acute angles; and the resulting trajectories correspond roughly to the equivalent Mach-Zehnder light interferometer. A magnetic or electrostatic field gradient across the two paths produces a path difference that is observable as a shifting of the interference fringes.

To demonstrate the feasibility of the wide-beam interferometry system, NBS performed light-optical analog experiments in which the optical path of the modified Mach-Zehnder type was reproduced by means of transmission-type gratings. This system constitutes a light-optical interferometer that is useful for computing the design characteristics of the electron-beam instrument. Further evidence for the soundness of the

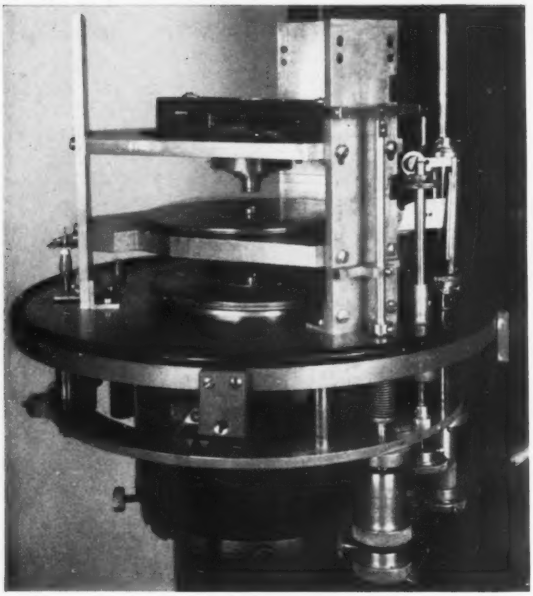
Adjusting electron-beam interferometer, which utilizes electron beams to produce interference fringes in much the same way as conventional optical interferometers use light beams. Three crystals are mounted in a vacuum chamber (center) placed between the illuminating and viewing systems of a conventional electron microscope. Each mount may be rotated about optical axis; the mount of the first crystal may also be translated along the optical axis. The controls for these motions are brought out at the bottom of the evacuated chamber.

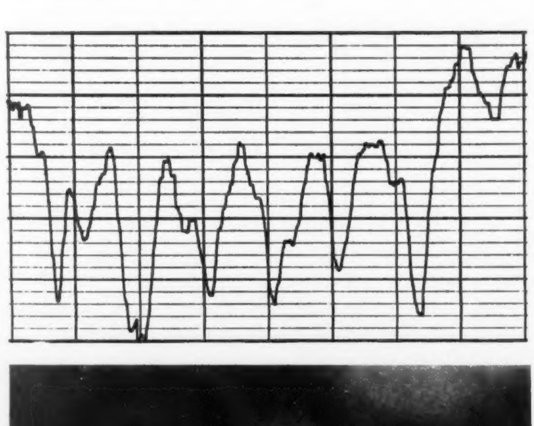
idea was furnished by the electron-microscope observations of interference fringes in thin crystals by Mitsuishi and Uyeda (Japan) and others. There was a general indication that the type of interference necessary for the operation of an electron interferometer may be produced in thin crystals.

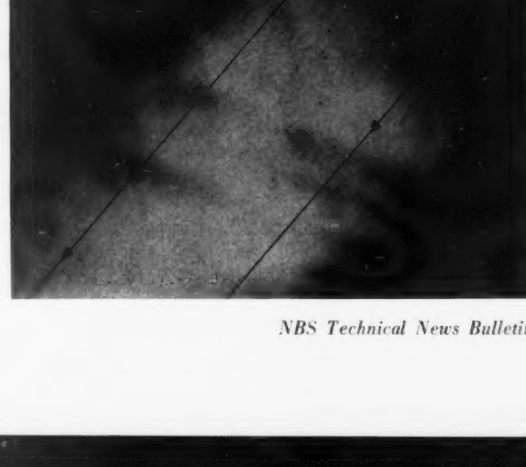
Because the electron beam must pass through three crystals, their thickness cannot exceed a few hundred angstroms, which makes the utilization of naturally occurring crystals almost prohibitive. Fortunately, it is possible to grow oriented layers of metal by evaporation on a foreign crystalline substrate. The process is known as epitaxy. One of the control conditions governing the production of crystals by epitaxy is the temperature of the substrate, the so-called epitaxial temperature, which is different for every metal-substrate pair. During the NBS experiments it was observed that for rock-salt substrate an approximately linear relationship exists between the epitaxial temperature and the most commonly occurring ionization potential of the metal. It was then possible to predict the critical temperature and to orient the atoms of gold, silver, nickel, copper, platinum or palladium on the substrate. Gold oriented more completely than nickel but did not have as high a mechanical strength to survive the process of mounting; hence, thinner nickel films were used. The crystals are made into $\frac{1}{8}$-in. disks less than 200 A thick; it is not known whether the disk is a single crystal or a mosaic of alined smaller crystals. But the important question is whether such gold or nickel films deposited on rock-salt cleavage faces are capable of splitting an electron beam while preserving coherence. Electron micrographs indicate that the image quality of the mesh supporting the crystal is preserved in the higher orders, which implies the preservation of coherence.

The crystal method of beam splitting imposes a stringent limitation on the angle between the beams and hence the angles of the crystals in the interferometer. For gold at electron energies in the range of 50 kev, the angle between beams is only about 70 min of arc. This fact limits the beam separation to the order of 1 mm in an instrument convenient for mounting in an electron microscope (involving intercrystal distances of 5 cm). The beam diameter, consequently, is limited to less than $\frac{1}{2}$ mm.

Each of the three crystal mounts in the NBS electron interferometer can be rotated about the optical axis. The mount of the first crystal may also be translated along the axis to change the path difference. The most recent experiments were conducted with a crystal spacing of 3.48 cm. Copper crystals approximately 100 A thick and about 3 mm in diameter are used. The limiting aperture in front of the third crystal is a small platinum disk with a 250-micron diameter hole

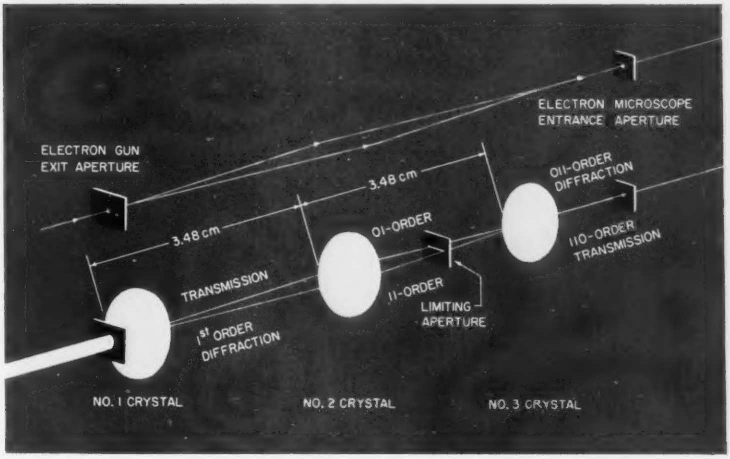






***Left:* Internal mechanisms of NBS electron-beam interferometer. Three crystals are mounted in an evacuated chamber that replaces the object chamber of an electron microscope. Each of the three crystals is placed on a mount that may be rotated about the optical axis. The mount of the first crystal (top disk) may also be translated. The spacing between crystals is 3.48 cm. Copper crystals approximately 100 A thick and about 3 mm in diameter are enclosed in small capsules that are placed in the center of the disk-like mounts. *Right:* Interference fringes obtained with electron-beam interferometer; arrows indicate their direction. The graph shows the magnitude of the fringes as measured by a microdensitometer.**

Sketch demonstrating diffraction of an electron beam through a series of three crystals mounted in the electron-beam interferometer. Part of the beam from the electron gun is limited by its exit aperture. The #2 crystal is cut and positioned to accept only the transmitted ray and one of the first-order diffracted rays. An aperture between the #2 and #3 crystals limits the electron beam to the 01 order diffracted ray and the 11 order diffracted ray passing through crystal #2. The electron microscope's entrance aperture limits the beam passing through crystal #3 to the 011 order ray and the 110 ray. The total path of these twice diffracted, once transmitted rays resembles a parallelogram (above) with two very acute angles.



drilled through the center. The interferometer vacuum chamber, containing the three crystal mounts, is designed to replace the object chamber of the magnetic electron microscope.

In the course of alining and testing the interferometer two difficulties are encountered. One is due to the use of diffraction as a beam splitting mechanism; the other results from the low intensity of the exit beam. Interferometers using diffraction both for beam splitting and beam deflection are capable of forming a higher-order fringe in a nonmonochromatic light. This "achromatic" property is fortunate in that it relieves the stringent necessity for power-supply stability over long exposures of the electron-optical instrument. On the other hand, it has the disadvantage of limiting the application of the instrument to problems in which the coherence properties of the source are of no interest. Consequently, the instrument in its present form may be used for wavelength determinations or field gradient investigations but may not be used as an interferometric spectrometer for the study of electron emitters. Different interferometric arrangements are necessary for the study of coherence phenomena and are currently being investigated.

The second difficulty, a very low beam intensity, arises because only a small part of the total beam diffracted at each of the three crystals is utilized. The initial intensity is limited by the small apertures of the objective lens, the fineness of the 50-micron mesh upon which the crystal is mounted, and the maximum temperature the crystal can withstand. At maximum beam intensity the electron-optical parts can be operated to give a direct electron optical magnification of about 700 diameters. The resolving power of the instrument under these conditions is limited to fringe spacings of the order of 1000 A both by the electron-optical system and by the grain of the photographic emulsion.

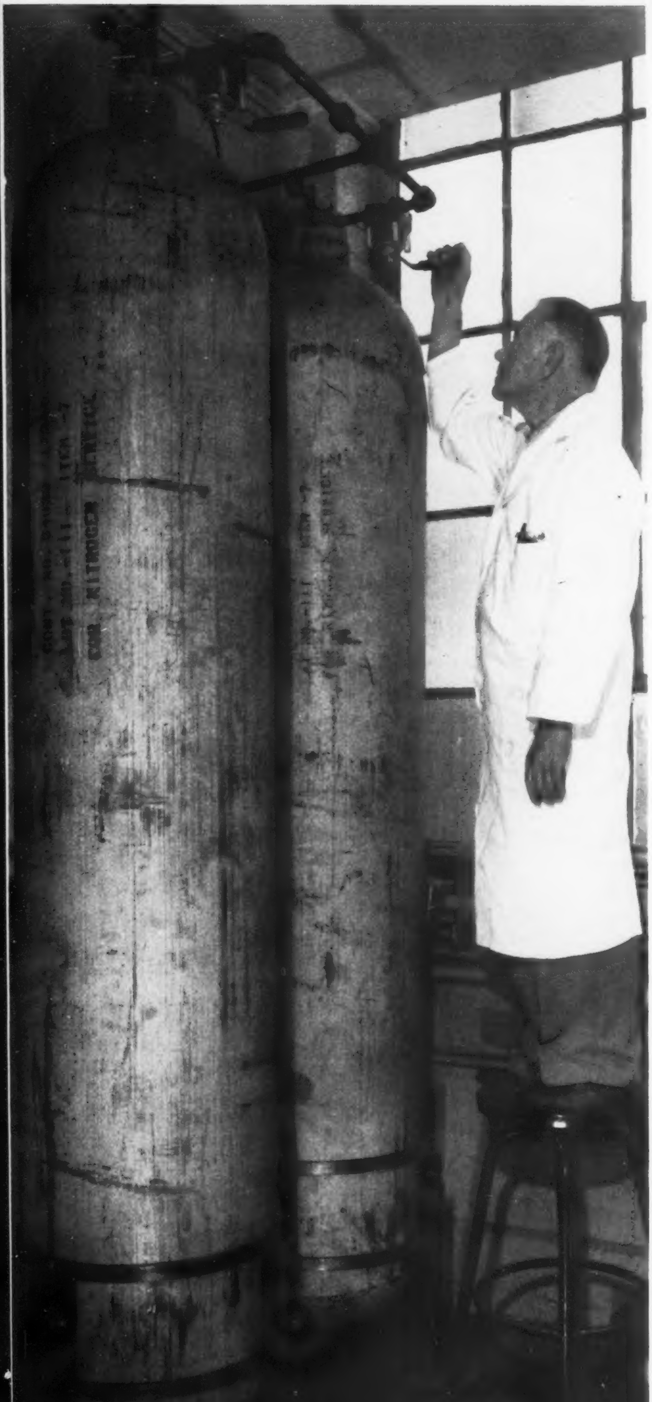
To prove that the observed fringes were actually those sought, calculations were made with nominal values of the important constants—grating constants and electron wavelength—associated with the interferometric system. The wavelength of 60-kev electrons was taken as 0.05 A and the effective grating space of the crystals as 2.5 A. With these values the maximum permissible angle of the wave-front leaving the instrument must be less than 54 sec of arc. Because of the very small angle involved in the operation of the electron microscope and the extreme skewness of the trajectory angles of the interferometer, this requirement can be met with angular adjustments no more accurate than 8 min of arc and linear adjustments no more accurate than 0.005 in.

To prove that the resulting interference fringes were due only to the geometry of the instrument, NBS staff members changed the geometry slightly and investigated the fringe behavior as a function of the changes. It was found that within certain limitations a rotation of the third crystal by 2½ deg produced an 8-deg relative rotation of the fringes. Several experiments were conducted in which the intercrystal distance between the first and second crystal was changed. The fringe spacing was found to vary as a function of the distance. Unfortunately, the fringes are difficult to discern, but it is believed that improved crystals will eliminate some of this difficulty. At present, the magnitude and number of fringes are obtained by use of a microdensitometer.

The original photographic record of interference showed 154 fringes with a mean spacing of 1650 A. By use of a light-optical analogy the difference between the two paths in the electron interferometer was calculated to be of the order of 6000 wavelengths. This preliminary value indicates that previous evaluations of the length of the electron wave train, based on diffraction experiments, should be extended by a factor of 30.

For further technical details, see Electron interferometer, *by L. Marton, Phys. Rev.* **85**, *No. 6, 1057 (1952), and* Electron beam interferometer, *by L. Marton, J. Arol Simpson, and J. A. Suddeth, Phys. Rev.* **90**, *490 (1953).*

For information concerning epitaxy, see Epitaxial deposits of metals evaporated on salt substrates, *by O. G. Engel, J. Research NBS* **50**, *5 (May 1953) RP2416.*



RECENT trends toward high-altitude flight and more efficient utilization of weight and space in aircraft have led to a much wider application of pneumatic systems for performing such high-speed operations as extending and retracting the landing gear, emergency canopy or seat ejection, gun charging, and rocket ejection.

Although compressed air has been used for many years, airborne pneumatics is still in an early stage of development. In view of the high actuation speeds and operating pressure now being considered, a comprehensive program of research and evaluation is needed. To meet this need a program for the study of high-pressure pneumatics has been established by the National Bureau of Standards at the request and with the cooperation of the Airborne Equipment Division of the Navy's Bureau of Aeronautics. Although primarily directed toward the needs of military aviation, the efforts of the pneumatics laboratory should find wide application in the aircraft industry as a whole and in other fields of high-pressure technology.

Under the direction of Dr. Milton M. Slawsky of the NBS Heat and Power Division, the pneumatics laboratory conducts research basic to the design and evaluation of compressors, storage tanks, accumulators,

HIGH-PRESSU

valves, and other airborne pneumatic equipment. It also obtains fundamental data in anticipation of future design requirements, develops laboratory procedures for the study of newly developed components, and renders technical assistance in the preparation of specifications for pneumatic devices.

Available facilities include a compressor system furnishing air at pressures up to 500 atmospheres, a specially designed low-temperature box for testing components at temperatures down to $-95°$ F at atmospheric pressure, and an altitude chamber capable of simulating conditions up to a height of 80,000 ft.

The altitude chamber has a working volume of approximately 25 ft^3—sufficient to accommodate an entire pneumatic system. Both temperature and humidity controls permit the simulation of flight conditions at high altitudes, and studies can be made over the entire temperature range from $-100°$ to $+150°$ F.

The low-temperature box contains a 3.75-ft^3 test chamber refrigerated by circulating alcohol from an adjacent bath chilled by dry ice. Air under pressure passes to the component under study through a built-in

Left: High-pressure storage tanks in the NBS pneumatics laboratory. Each tank contains 10 ft^3 of air under a pressure of 3,000 lb/in^2. Right: Calibration of a bank of static-pressure gages in the pneumatics laboratory. Pressure acting on the gages (upper right) is balanced against the pull of gravity on weights supported on the piston of a precision dead weight gage (lower left).

A part of the pneumatics laboratory compressor system. Air from this compressor, rated at 25 standard ft^3/min, and from another, rated at 7.5 scfm, is stored at 3,000 lb/in^2 and piped to the test stands, allowing continuous operation of facilities throughout the working day.

cooling coil. A flow of 150 standard ft^3/min can be maintained through the system for extended periods at $-90°$ F.

The evaluation of pneumatic systems and components involves measurements of pressure and temperature under transient, pulsating, and steady-flow conditions as well as the measurement of volume rate of steady flow. The equipment used by the pneumatics laboratory for this work has been designed to permit automatic recording, versatility, and mobility wherever possible. Static pressures are measured by a bank of bourdon-type gages that are calibrated at frequent intervals against a dead-weight piston gage capable of extreme accuracy over the range of pressures from 25 to 6,000 lb/in^2. Transient pressures are determined by means of temperature-compensated strain-gage pressure pickups calibrated at static pressures. The strain gage is employed in the usual manner, but the signal is fed either into a recording potentiometer (for

PNEUMATICS

slow transients) or through a strain-gage amplifier to an oscilloscope (for fast transients). Chromel-alumel thermocouples are used to measure temperature. To decrease response time, they are made of 36-gage wire with as small a junction as possible. For measurements in high-pressure air streams, the thermocouple is built into a high-pressure gland.

The work of the pneumatics laboratory in the evaluation of pneumatic systems has been concentrated on two problems: (1) Determination of the factors governing

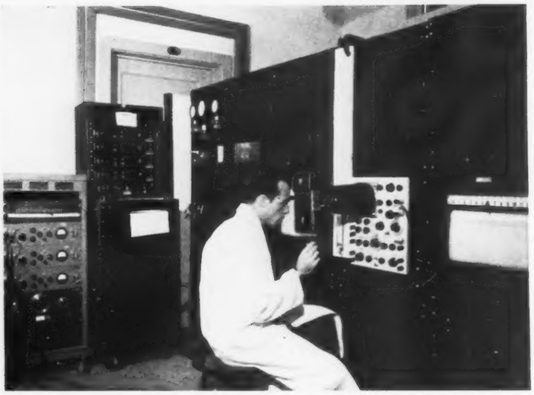
the most efficient storage and working pressure and (2) determination of the pressure and energy losses in pneumatic systems during transient flow.

Preliminary calculations on the first of these problems indicate that storage pressures of 3,000 lb/in^2 are justified and that perhaps even higher pressures may yield further savings in weight and space, but with diminishing returns. The problem is complicated by the variety of possible systems, but there is reason to believe that a rational basis for estimating the optimum storage and working pressure can be developed.

The work on the second problem involves first the study of pressure and energy losses in a pneumatic system during steady flow and then the correlation of these losses with those occurring during transient flow. The results to date give a satisfactory agreement between theory and experiment for steady flow. From a practical standpoint, this means that it is possible to make an *a priori* estimate of the losses to be expected in any given pneumatic system. The theoretical calculations are now being extended to include experimental results obtained under transient-flow conditions.

Although the primary objective of the pneumatics laboratory is the solution of practical problems in pneumatic design, basic information must be gathered and analyzed in order to understand the relative importance of various design parameters. The laboratory is therefore conducting parallel theoretical and experimental investigations on the physical phenomena associated with the thermodynamics and mechanics of fluid flow.

At present the only published data on the high-pressure properties of air are the Joule-Thomson measurements, which extend to 220 atmospheres. To obtain the data that are needed in this field, the NBS Thermodynamics Section has installed laboratory facilities and apparatus for measuring the pressure-volume-temperature relations of air from the lowest temperatures to 350° K (170° F) and at pressures up to 300 atm. With the application of existing theory, the experimental measurements obtained in this range



A high-speed camera focused on a cathode-ray oscilloscope is used to record rapidly changing pressures.

will permit accurate determination of the thermodynamic properties of air at the high pressures being considered for future designs. The apparatus can also be used for PVT measurements on other technically important gases that have been considered for pneumatic applications.

On the basis of the existing data for the principal constituents of air and the limited data for air itself, tentative tables and charts of the thermodynamic properties of air have been calculated from 2 atm to 5,000 lb/in^2. The Joule-Thompson coefficient, specific heat, enthalpy, and entropy have been computed as functions of temperature and pressure; and graphs are in preparation.

Study of a large variety of pneumatic components at NBS has brought to light several inadequacies in current pneumatic testing practice. Some of the commonly accepted definitions and test procedures have proved to be ambiguous; as a result, it has been necessary to reexamine the bases on which existing tests were set up. A careful analysis has been made of the performance of various components to determine the elements or characteristics that are of real importance to their proper operation.

In the course of this work, a method was worked out for describing the pressure drop across any pneumatic component in terms of a single characteristic curve.[1] This new approach permits the rating of a valve with extreme economy of time and much less ambiguity. Previously the flow characteristics of a component were described by a family of flow curves, which were plots of flow rate versus downstream pressure for various values of upstream pressure. Numerous careful measurements were necessary to provide the data for such a set of curves. NBS workers investigating the problem found that when the ratio of the downstream pressure to the upstream pressure is plotted against the ratio of the flow rate to the upstream pressure, a characteristic curve is obtained which is unique for the component under study.

Moreover, inasmuch as analytical formulas are available for plotting these characteristic curves and they all have one point in common, any given characteristic curve is completely determined by specifying one other point. Thus, the NBS study shows that the complete behavior of a pneumatic component can be specified simply by the measurement of a single value of the flow rate for a given value of the ratio of downstream to upstream pressure. The value of the flow rate where the ratio of pressures is $\frac{1}{2}$ has been designated the "flow factor" and is used by the Bureau to describe the complete behavior of a pneumatic valve in terms of a single quantity. The flow factor is a constant for a given component; and once it is determined, either by experiment or theory, it can be used to predict valve performance for a wide range of upstream conditions. It is also possible to combine analytically the flow factors of a number of valves into an overall flow factor, which will serve to determine the behavior of the more complex system composed of the separate valves in series.

In the short time since its establishment the NBS pneumatics laboratory has made progress in the development of facilities, instrumentation, and experimental and theoretical techniques for the analysis of pneumatic systems. The laboratory has made a continual effort to maintain a balance between the practical and sometimes urgent requirements of the designer and the more basic aspects of the problems studied. It is felt that time spent on the more fundamental studies will eventually be of great value in the solution of technical problems arising in pneumatic systems where high flow rates, short response time, and rigid cycling schedules are specified.

Mobile instrument and control panels for measurement of high-pressure flow in the NBS pneumatics laboratory.

[1] *A method for predicting pressure drops in pneumatic systems,* by M. M. Slawsky, A. E. Schmidlin and Molutzky, Soc. Automotive Engrs. Preprint No. 81 (1953)

Frequency Deviation Meter

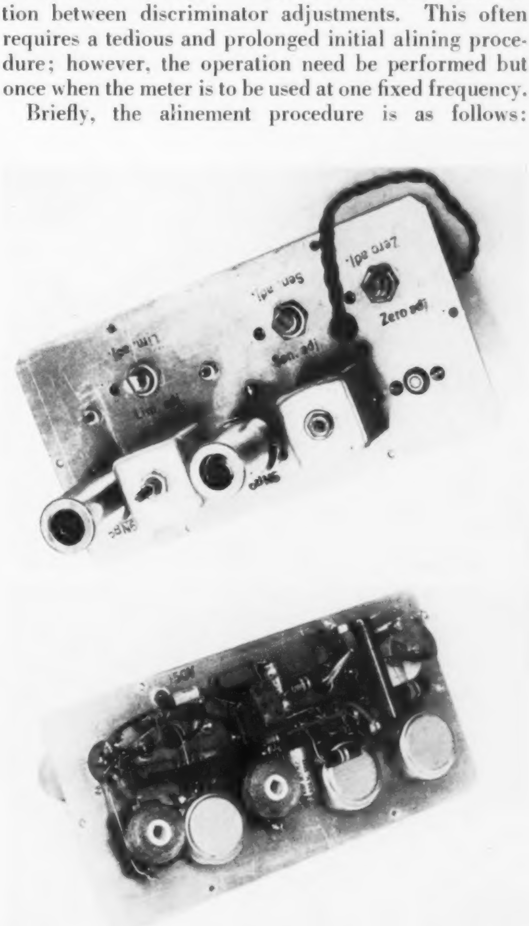
TO PROVIDE more reliable and sensitive receiving and recording instruments for communications signals, the Bureau has for some time carried on a continuous program of research and development in this field. Most recent product of the program is a comparatively simple frequency-deviation meter developed by Norris Hekimian of the NBS Central Radio Propagation Laboratory. The instrument indicates the deviations of a signal from a reference frequency to better than 0.5 percent. It performs the same function as the "tuning eye" on some regular radio broadcast receivers but with sufficient precision to be used in the laboratory or as part of the production inspection procedure in a manufacturing operation.

As is true of most frequency-deviation meters, the circuit of the NBS instrument consists of a limiter-discriminator arrangement and provision for driving an indicating device from the discriminator output. Normally the arrangement includes two stages of limiting, one of discrimination and a driving stage. However, by use of the new 6BN6 gated-beam tubes it has been possible to reduce circuit complexity and to hold the tube complement to two in number. Advantage is taken of the input-output characteristics of the 6BN6 tube, which rises sharply to an equilibrium level, as in a step function, to obtain the second stage of limiting combined with quadrature-grid discrimination. The indicating device—a 150–0–150 microammeter—is driven through a d-c bridge circuit by the current resulting from an unbalanced condition in the plate circuit of the discriminator. The circuit unbalance arises when the input signal differs from the zero-set or reference signal.

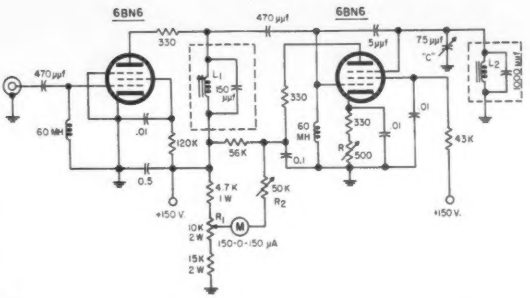
To avoid plate-current cutoff by self bias, which is possible with gated-beam tubes, the NBS circuit employs 60-millihenry chokes in the signal grid returns of the 6BN6 tubes. Low-value resistors are placed in the plate leads to help dampen the plate surges and to aid in obtaining a flat limiter characteristic. A well regulated plate supply operating at 150 v has a current drain of only 10 ma. For more stable operation the heater supply is also regulated. Circuit components are not critical, but stable elements reduce maintenance problems. The d-c bridge resistors in the indicator circuit are of adequate wattage and sufficiently well ventilated to avoid changes in resistance from overheating. The tank coil in the plate circuit of the first stage is set to resonate at the center or reference frequency and has a Q of about 60 when adjusted on a meter external to the circuit. The quadrature-grid tank coil also resonates near the center frequency and has a Q of 100 when measured out of the circuit. Because the quadrature tank determines the reference frequency of the deviation meter, it is enclosed to protect it from harsh handling and from being overheated by neighboring power resistors.

The NBS circuit has two inherent disadvantages: (1) Because the current flow in the grid of the first 6BN6 is limited, the input impedance of the meter varies with the level of the input signal and has a minimum value of about 10,000 ohms. This relatively large minimum is generally acceptable, but a low-output impedance driver, such as a cathode follower, may be used when necessary as a buffer between the signal source and the deviation meter. (2) Like many other discriminators, the NBS unit shows considerable interaction between discriminator adjustments. This often requires a tedious and prolonged initial alining procedure; however, the operation need be performed but once when the meter is to be used at one fixed frequency.

Briefly, the alinement procedure is as follows:



The compact NBS frequency deviation meter performs the same function as the "tuning eye" on some regular radio broadcast receivers. The top side of the meter (above) has screw-driver controls for adjusting the zero setting, the sensitivity, the limiting characteristics, and the capacitance and inductance of the resonant circuits. The underside of the meter (below) shows the coils of the resonant circuits and associated components.



Circuit diagram of frequency-deviation meter, a comparatively simple device that indicates deviations of a signal from a reference frequency to better than 0.5 percent.

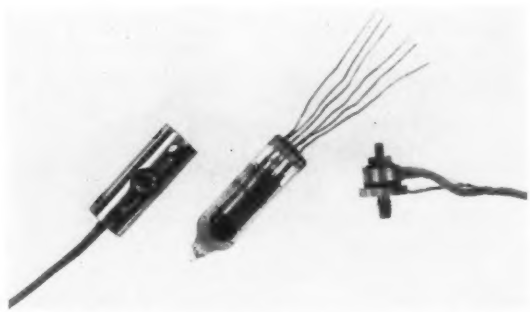
(1) The indicating meter is replaced by a high-impedance voltmeter, and the direction of the needle swing is noted for increasing input signal from 0 to 1 v. The plate coil of the first stage is then tuned for maximum voltmeter reading in the noted direction. During this period, the input potential is maintained at the lowest value that will allow readable output changes. (2) The zero control of the d-c bridge and the tank capacitor in the quadrature grid are adjusted simultaneously for approximately a normal discriminator curve as the signal generator frequency is slowly varied about 10 kc on either side of the desired mean frequency. (3) With the input signal set at the desired mean frequency, the input level is slowly varied from about 0.2 to 2.0 v, and the cathode resistor in the output stage is adjusted for the flattest limiter characteristic obtainable. The signal generator frequency is monitored continuously with a stable receiver and beat oscillator to insure that the frequency does not vary when the output is changed. (4) The high-impedance voltmeter is replaced by the indicating meter, and steps (2) and (3) are repeated to obtain the desired symmetrical discriminator characteristic and good limiting.

Calibrations may be performed in several ways depending on the equipment that is available. When a well calibrated signal generator may be used, it is necessary to calibrate only the output indicating meter directly against the input frequency of the signal generator. The input to the deviation meter should be set to at least 2.0 v during the calibration.

One of the NBS frequency deviation meters was used during a 1,600-hr continuous life test to determine the difference between the local and signal oscillators in two 30-Mc receivers. At the conclusion of the examination the deviation meter showed a change of less than 200 cycles, which was probably due to changes in the crystal oscillators of the receivers. No adjustment to the deviation meter was necessary after the initial calibration.

For further technical details, see Frequency-deviation meter plots drift, *by N. C. Hekimian, Electronics* **25**, *6, 134 (June, 1952).*

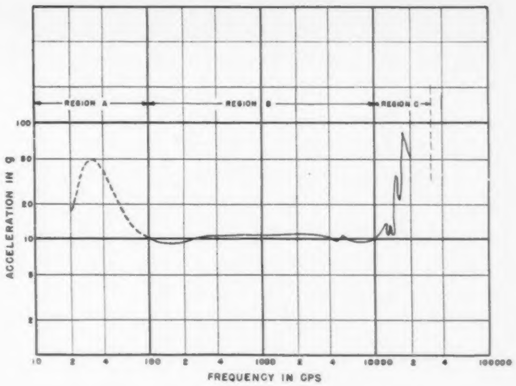
Vibration Generator for Electron Tubes



Left: **Subminiature-tube-type accelerometer devised as aid to development of tube vibrator. In both shape and weight accelerometer conforms closely to a subminiature electron tube. *Center:* One of subminiature tubes being studied for microphonics at NBS. *Right:* This previously developed miniature wide-range vibration pickup made possible the development of the NBS tube vibrator.**

ELECTRONIC equipment is being called upon increasingly for applications where it is subjected to severe shock and vibration, and engineers have had to develop special components rugged enough to withstand such strenuous service. Electron tubes are a particular problem from the standpoint of severe vibration. In addition to being strong enough not to fail mechanically, the tube must be low in microphonics: spurious electrical signals generated by vibration of the tube must be low in relation to the desired signal that the tube is handling. In ordinary receiving tubes, microphonics may easily be a thousand or even a million times greater than the intrinsic tube noise. Tube microphonics can be a particularly difficult problem in miniaturized equipment.

An improved wide-range vibration generator is facilitating the study of low-microphonic tubes in the electron tubes laboratory of the National Bureau of Standards. Recently developed by J. D. Rosenberg, W. B. Hillstrom, and L. T. Fleming, the NBS tube vibrator produces accelerations up to 20 times that of gravity and is flat within 20 percent over the unusually wide range of 100 to 10,000 cycles per second. The



Frequency response curve of the NBS tube vibrator. Response is substantially flat from 100 to 10,000 cycles.

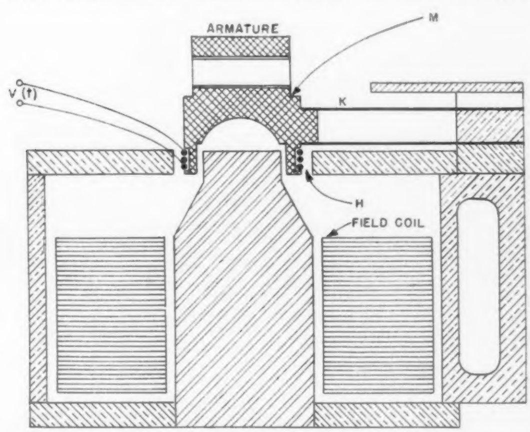
tube under study is fitted into a hole in the vibrator's moving element, or armature. The armature is a cylindrical block of nonmagnetic material with a "voice coil"—for the audio-frequency driving voltage—at its lower end. Two flexible metal strips hold the armature centered in an electromagnetic field structure powered by 40 w of 120-v direct current. Although the only model of the NBS tube vibrator thus far constructed was built to accomodate subminiature-type tubes, the design could readily be modified for microphonics studies of miniature or octal tubes.

Commercially available vibration generators of the mechanically driven type have upper frequency limits of only about 300 cps; they are primarily vibration fatigue testers, having irregular waveform and lacking the flexibility required for development work. Commercial vibrators of the electrodynamic or "loudspeaker" type are seldom useful at frequencies above 3,000 cps. The moving coil in this type of vibrator is usually fastened to a drive rod that typically has objectionably sharp resonances in the neighborhood of 2,000 cps.

In the NBS vibrator the upper frequency limit is raised by making the armature simple and rugged, of a material having a high ratio of rigidity to weight. Linen bakelite, which is only moderately good in this particular respect, was used for the present armature in the NBS vibrator because of its convenience and availability. The fundamental resonance occurs in the neighborhood of 18,000 cycles; response begins to rise at about 10,000 cycles. Use of a material with a higher rigidity-to-weight ratio would substantially raise the frequency of fundamental resonance and thus the upper limit of flat response.

Development of the NBS tube vibrator was dependent upon the previous development of a small barium titanate accelerometer (NBS Model 3) capable of measuring vibration frequencies to 20 kilocycles at acceleration levels of 0.2 to 10,000 *g*.[1] One of these accelerometers is mounted on the armature of the vibrator to sense the vibration amplitude.

Cross-sectional drawing of essentials of tube vibrator.

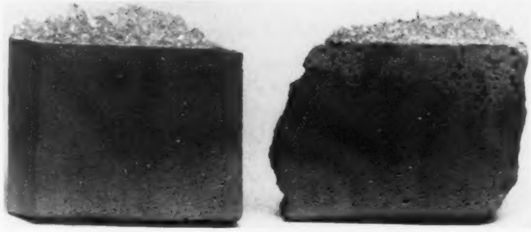


Another barium titanate accelerometer, similar in shape and weight to a T–3 subminiature tube, was developed expressly to meet needs arising in the development of the vibrator. The problem was how to design a convenient tube holder for the vibrator, sufficiently free from stray compliances and resonances to assure that the motion of the tube would conform closely to the motion of the vibrator up to at least 10 kc. The subminiature-tube-type accelerometer facilitated the design of a tube holder meeting this requirement.

[1] *Miniature piezoelectric accelerometer*, NBS Tech. News Bull. **35**, 141 (Oct. 1951).

Inserting experimental subminiature tube into the wide-range tube vibrator. The tube fits into a mounting that is an integral part of the vibrator's armature. Two light phosphor-bronze leaf suspensions (right) center the armature in the field of an electromagnet, permitting vertical motion when audio-frequency power is applied to a coil wound around the bottom of the armature.

Permeability of Firebrick



Specimens from two refractory clay pots used for melting optical glass. In the specimen at the right the molten glass has penetrated extensively into the body of the pot, as indicated by the difference in shading; the specimen at the left shows none of this difficulty.

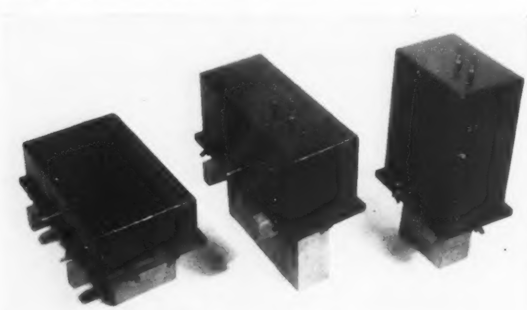
USING a permeameter of improved design, the National Bureau of Standards has recently completed a study of the permeability to air of various firebricks and of refractory-clay pots used for melting glass. The permeameter provided an easy and accurate means of determining the relation between the pressure gradient across two opposite faces of a test specimen and the rate of air flow through the specimen. Bulk densities, moduli of elasticity, and porosities were determined in addition to flatwise, edgewise, and endwise permeabilities. The permeability of the glass-melting pots was found to be a good criterion of their resistance to penetration by molten glass, and this was perhaps the most interesting finding from the standpoint of direct practical application. However, the firebricks were the principal focus of the study, which was conducted by G. B. Massengale, L. E. Mong, and R. A. Heindl of the NBS refractories laboratory.

Permeability is expressed in terms of the flow of air in cubic centimeters per second that will pass through two opposite faces of a 1-cm cube, when the pressure between the two faces of the specimen differs by 1 g/cm^2. Information on the significance of permeability of refractory materials has been rather limited, but its possible importance has not been overlooked. For instance, highly permeable refractory bricks have been selected for the construction of furnaces of improved efficiency. Also, it has been suggested that manufacturers of refractories might be able to control closely the uniformity of their products by maintaining uniform permeability. It has been suggested, too, that permeability may be important in determining the resistance of refractories to molten glass, alkali vapor, carbon monoxide, and molten slag, and in determining heat losses due to flow of hot gases through the walls of refractory installations. The NBS investigation was undertaken primarily to obtain more definite information about room-temperature permeabilities of firebricks manufactured in the United States.

The permeameter developed for the NBS study is a modification of a permeameter described by Ketchum, Westman, and Hursh, but has advantages not offered by those previously described in the literature. A specimen to be tested is placed in a "seal box" arranged to permit air under pressure to be applied to one face so that it flows through the brick and out into the room at the opposite face; the other four faces are sealed with a soft rubber inner tube inflated with sufficient pressure to prevent air from escaping. The rate of air flow through the brick and the pressure difference between the two nonsealed faces are measured, and from these data the permeability is readily calculated.

The air supply is furnished by a compressor. After passing through a trap and filter, three pressure regulators, and two drying towers, the air enters a flow

For measurement of flatwise, edgewise, and endwise permeabilities of firebrick three seal boxes were required. In each case air under pressure enters the top of the box through one of the two fittings, passes through the brick from upper horizontal face to lower horizontal face, and flows out into the room through the open bottom of the box. When under test, the bricks are completely enclosed in the boxes.



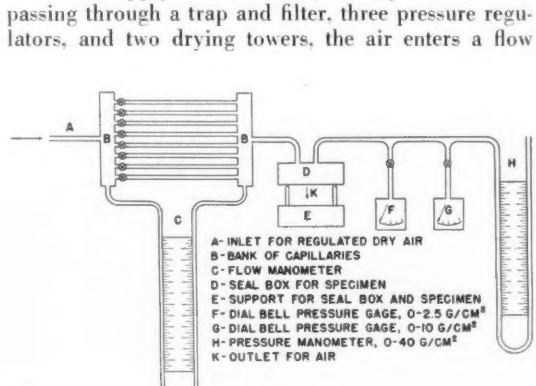
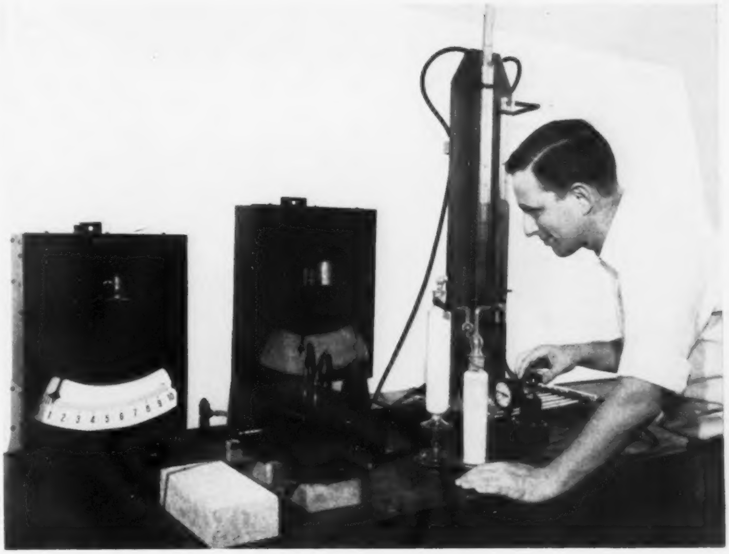


Diagram of improved permeameter devised for measuring permeability of firebrick to air at room temperature.

Measuring permeability of a firebrick (concealed within rectangular black seal box, center foreground) to air with an improved permeameter. Air under pressure enters top of seal box after passing through driers and flowmeter (right). From top of box air flows through the brick, flowing out of lower surface of the brick and out of open bottom of seal box at room pressure. A rubber inner-tube arrangement fits snugly over the brick inside seal box and is inflated with compressed air by means of tube entering at left of box; four vertical sides of brick are thus sealed so that no air flows through them. Two pressure gages (rear left and center) and a pressure manometer (right rear) are connected to top of seal box to indicate pressure difference, over three ranges, between top and bottom of specimen.



meter. This device consists of one or more capillary tubes connected across a kerosene manometer; with proper calibration, the pressure difference between the ends of the capillaries, as indicated by the manometer, gives the rate of flow. From the flow meter the air enters the top of the seal box containing the test brick. Pressure difference between the top and bottom surfaces of the brick is indicated by two low-range pressure gages and a higher-range manometer, all connected to the top of the seal box. Flow rates per unit pressure drop across specimens have been accurately determined for a range from 0.00114 to 542 units with this permeameter.

Permeabilities were determined for some 11 types of firebricks: Insulating, super-duty fire-clay, high-duty fire-clay, mullite, acid-proof, silica, magnesite, chrome-magnesite, magnesite-chrome, kaolin, and 60-percent alumina. Permeability was generally lower flatwise than edgewise or endwise, probably because most of the firebricks were made by the dry-press process. Correlation between permeability and the other determined properties was low, but there was some tendency for higher permeability to be associated with higher porosity and with lower bulk density and modulus of elasticity. Specimens of some unburned bricks with organic binders were measured both before and after heat treatment; their permeability was greatly increased by 1,600° C heat treament. Permeability was much more sensitive to heat treatment than were porosity, bulk density, and modules of elasticity.

Similar measurements were made on specimens cut from three slip-cast refractory-clay pots of the type used for making optical glass. Pots that in service showed high resistance to penetration by molten glass were found to be characterized by fine grain sizes and low permeability; high measured permeability was associated with high penetrability by molten glass. Permeability was a better criterion for resistance to attack by molten glass than was modulus of elasticity, porosity, or bulk density.

For further technical details, see Permeability and some other properties of a variety of refractory materials, *by G. B. Massengale, R. A. Heindl, and L. E. Mong, J. Am. Ceram. Soc. (July and August, 1953).*

Publications of the National Bureau of Standards

Periodicals

Journal of Research of the National Bureau of Standards, volume **50,** number 6, June 1953 (RP2419 to RP2425 Incl.). Annual subscription, $5.50.

Technical News Bulletin, volume **37,** number 6, June 1953, 10 cents. Annual subscription, $1.00.

CRPL–D106. Basic Radio Propagation Predictions for September 1953. Three months in advance. Issued June 1953, 10 cents. Annual subscription $1.00.

Research Papers

Reprints from Journal of Research, volume **50,** *number 6, June 1953. These reprints may be obtained only in quantities of 100 or more from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Prices will be quoted by the Superintendent of Documents.*

RP2419. Electron microscopy of synthetic elastomer latices. Robert R. Stromberg, Max Swerdlow, and John Mandel.

RP2420. Second-order transitions of rubbers at high pressures. Charles E. Weir.

TECHNICAL NEWS BULLETIN

U. S. DEPARTMENT OF COMMERCE

SINCLAIR WEEKS, *Secretary*

NATIONAL BUREAU OF STANDARDS

A. V. ASTIN, *Director*

July 1953 Issued Monthly Vol. 37, No. 7

For sale by the Superintendent of Documents .U. S. Government Printing Office, Washington 25, D. C. Subscription price, domestic, $1.00 a year; foreign, $1.35; single copy, 10 cents. The printing of this publication has been approved by the Director of the Bureau of the Budget, March 6, 1953.

Contents

RP2421. Thermodynamics of the rubber-sulfur system at high pressures. Charles E. Weir.

RP2422. Laboratory measurement of the corrosion of ferrous metals in soils. W. J. Schwerdtfeger.

RP2423. Effect of temperature on the electrical resistance and voltage departures (errors) of glass electrodes, and upon the hygroscopicity of glass. Donald Hubbard.

RP2424. On the numerical solution of parabolic partial differential equations. Gertrude Blanch.

RP2425. Thermal properties of some butadiene-styrene copolymers. George T. Furukawa, Robert E. McCoskey, and Gerard J. King.

CIRCULARS

C540. Weights and measures case reference book. (Through July 1953 court decisions.) Kathryn M. Schwarz. $1.25.

APPLIED MATHEMATICS SERIES

AMS20. Tables for rocket and comet orbits. Samuel Herrick. $1.75.

AMS26. Table of arctan x. $1.75.

PUBLICATIONS IN OTHER JOURNALS

Pulp and paper. Robert B. Hobbs and William K. Wilson. Chem. and Eng. News (1155 Sixteenth Street NW, Washington 6, D. C.) **31**, No. 1, 40 (January 5, 1953).

FM data reduction from magnetic tape recordings. Louis Costrell. Rev. Sci. Instr. (57 East Fifty-fifth Street, New York 22, N. Y.) **24**, No. 1, 76 (January 1953).

Plastic electrets. H. H. Wieder and Sol Kaufman. J. App. Phys. (57 East Fifty-fifth Street, New York 22, N. Y.) **24**, No. 2, 156 (February 1953).

Standard samples. Edward Wichers. Science (1515 Massachusetts Avenue NW, Washington 5, D. C.) **117**, No. 3027, 3 (January 2, 1953).

The operating characteristic of the average chart. Edgar P. King. Ind. Qual. Control (70 East Forty-fifth Street, New York 17, N. Y.) **9**, No. 3, 30 (November 1952).

Relations among certain specification properties of building brick and effects of differences in raw materials and methods of forming. J. W. McBurney, J. C. Richmond, and M. A. Copeland. J. Am. Ceramic Soc. (2525 North High Street, Columbus, Ohio) **35**, No. 12, 309 (December 1952).

Diaphragm error and testing rate in the paper bursting test. F. T. Carson and Vernon Worthington. Tappi (122 East Forty-second Street, New York 17, N. Y.) **35**, No. 12, 539 (December 1952).

Transmission loss in radio propagation. K. A. Norton. Proc. IRE (1 East Seventy-ninth Street, New York 21, N. Y.) **41**, No. 1, 146 (January 1953).

A high-power pulse generator. W. E. Williams, Jr. Radio-Electronic Eng. Section, Radio and Television News (366 Madison Avenue, New York 17, N. Y.) **49**, No. 4, 32 (April 1953).

UHF magnetic attenuator. Frank Reggia. Radio-Electronic Eng. Section, Radio and Television News (366 Madison Avenue, New York 17, N. Y.) **49**, No. 4, 12 (April 1953).

Decay constant in vibrating systems. R. D. Laughlin. Radio-Electronic Eng. Section, Radio and Television News (366 Madison Avenue, New York 17, N. Y.) **49**, No. 4, 11 (April 1953).

An accurate time-modulated pulse circuit. Carroll Tschiegg and Martin Greenspan. Rev. Sci. Instr. (57 E. Fifty-fifth Street, New York 22, N. Y.) **24**, No. 2, 183 (February 1953).

The vapor pressure of He^3–He^4 mixtures. Raymond A. Nelson and William Band. Phys. Rev. (57 E. Fifty-fifth Street, New York 22, N. Y.) **88**, No. 6, 1431 (December 1952).

A variable length re-entrant cavity for dielectric measurements from 100 to 400 Mc. James H. Beardsley. Rev. Sci. Instr. (57 E. Fifty-fifth Street, New York 22, N. Y.) **24**, No. 2, 180 (February 1953).

Cracking in masonry caused by expansion of mortar. J. W. McBurney. Proc. ASTM (1916 Race Street, Philadelphia 3, Pa.) **52**, 1228 (1952)

The electromagnetic field of a rotating uniformly magnetized sphere. Alfredo Banos, Jr. and Robert K. Golden. J. App. Phys. (57 E. Fifty-fifth Street, New York 22, N. Y.) **23**, No. 12, 1294 (December 1952).

Synthetically bonded molding sand. Mary T. Zemantowsky. Am. Foundryman. (616 S. Michigan Avenue, Chicago, Ill.) **23**, No. 2, 57 (February 1953).

Report of the committee on atomic weights of the Am. Chem. Soc., Edward Wichers. J. Am. Chem. Soc. (1155 Sixteenth Street, NW., Washingon 6, D. C.) **74**, 2447 (1952).

A reliable locked-oscillator pulse timer. Peter G. Sulzer. Tele-Tech. (480 Lexington Avenue, New York 17, N. Y.) **12**, No. 4, 68 (April 1953).

Publications for which a price is indicated are available only from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. (foreign postage, one-third additional). Reprints from outside journals are not available from the National Bureau of Standards but can often be obtained from the publishers.

ge
07
00
01
04
07
08
10
11

oc.
1,

io-
66
ril

nic
on
3).
io-
366
11

egg
fth
3).
son
ew

nts
str.
180

W.
hia

zed
pp.
No.

ky.
ll.)

em.
nth

ele-
12,

etin